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# Optimal Dispatch of an Industrial Microgrid with a Mixed Portfolio of Distributed Energy Resources

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## I. Introduction

Local brownouts are a nuisance and have driven consumers to take greater responsibility for their electricity supply – particularly industries and communities with a critical need for reliable and safe power. By deploying a Microgrid on their own site, the consumers could benefit from having this interoperable grid solution with respect to improved energy efficiency, system reliability and power quality. When the on-site generation is from renewables, external incentives and system sustainability could make the Microgrid solution even more attractive.

One of the representative industrial Microgrid solutions, as depicted in Figure 1, is a steel mill-centered industrial Microgrid that is currently under construction in Laiyuan county of China. Historically, the 42MW load mixture of the steel factory includes inductive motors, electric furnaces and air-blowers and is supplied by the external grid through a 110KV distribution feeder together with a small factory-owned gas turbine. Due to its weak connection to the external grid, the voltage profile at the factory side can often drop below the desired voltage level (i.e., 10.5KV) by more than 5%. To improve the customer's voltage quality and to meet a projected load increase, the steel mill-centered industrial Microgrid solution is deployed to address these challenges by severing part of the factory's load. Meanwhile, under the support of the Chinese and Danish government jointly developed Renewable Energy Development (RED) programme, some advanced features for wind/PV/Storage constituted hybrid industrial Microgrid applications are being developed and to be demonstrated [1].

In this study, an optimal dispatch solution for a 1MW/5MWh lithium-ion battery system is developed and analyzed for its application in this industrial Microgrid. The hourly dispatch strategy takes into account the energy forecast of renewables and targets on achieving two objectives: 1) reducing the amount of energy exported to the



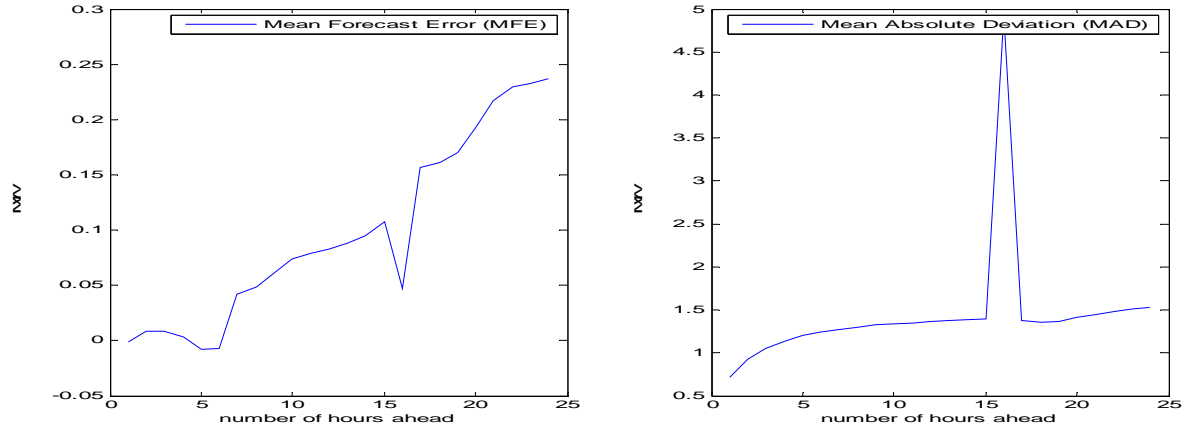


Figure 2. Accuracy analysis of the energy export forecast

### III. The time-of-use electricity tariff in China

Electricity prices in Laiyuan currently follow a time-of-use (TOU) policy as depicted in Table 1. For an electrical storage application, the TOU policy offers it a unique opportunity to perform energy arbitrage for achieving better economy. Compared to other arbitrage-based storage applications in Europe and U.S., the non-existence of deregulated electricity market in China further reduces the risk caused by price forecast errors as the TOU tariff typically remains the same for long.

Table 1: Electricity tariff in Laiyuan, China

|                      | Peak          | Shoulder                       | Flat  | Valley       |
|----------------------|---------------|--------------------------------|---|--------------|
| Time                 | 20:00 – 22:00 | 10:00 – 12:00<br>15:00 – 17:00 | 8:00 – 10:00<br>12:00 – 15:00<br>17:00 – 20:00<br>22:00 – 24:00 | 24:00 – 8:00 |
| TOU tariff (RMB/MWh) | 753.4         | 726.7                          | 510.6   | 316.4        |

### IV. Dispatch strategy formulation

The optimal dispatch strategy for the battery storage can be formulated as a typical  $N$  periods oriented optimization problem with multiple objectives as (1), wherein  $\lambda$  is the weighting factor between the two cost parts, i.e.,  $Cost_{ar}$  and  $Cost_{ex}$  representing the cost for battery's energy arbitrage and the cost for energy exchanged with the external grid respectively.

$$\min \sum_{i=1}^N (Cost_{ar} + \lambda \cdot Cost_{ex}) \quad (1)$$

The set of constraints for such a problem is formulated as (2) which includes the equations for cost, energy balance and power limits of the battery in each time slot  $i$ .

$$\begin{cases} Cost_{ar} = \Delta E_c(i) \cdot Q(i) \cdot \frac{u_1(i)}{\eta_c} + \Delta E_d(i) \cdot Q(i) \cdot u_2(i) \cdot \eta_d \\ Cost_{ex} = \Delta EX(i) \cdot (Q(i) + Q'(i)) \\ \Delta EX(i) = E_{load}(i) - E_{wind}(i) - E_{PV}(i) \\ E(i) = E(i-1) + \Delta E_c(i) \cdot u_1(i) + \Delta E_d(i) \cdot u_2(i) \\ \delta_{min} \cdot E_{nom} \leq E(i) \leq \delta_{max} \cdot E_{nom} \\ 0 \leq \Delta E_c(i) \leq P_{c,max} \cdot \eta_c \cdot \Delta t \\ -\frac{P_{d,max}}{\eta_d} \cdot \Delta t \leq \Delta E_d(i) \leq 0 \\ u_1(i) + u_2(i) = 1 \end{cases} \quad (2)$$

Decision variables  $\Delta E_c(i)$  and  $\Delta E_d(i)$  represent the energy charged into and discharged from the battery in each time interval respectively, which are limited by the maximum charging power  $P_{c,max}$  and discharging power  $P_{d,max}$  as well as the corresponding efficiency  $\eta_c$  and  $\eta_d$ . Meanwhile, two binary variables  $u_1(i)$ ,  $u_2(i)$  are introduced to indicate the corresponding charging/discharging status. The operational boundary of the battery's state of charge (SOC) is described by  $\delta_{min}$  and  $\delta_{max}$ . The intermediate variable  $E(i)$  represents the battery's energy status at the end of time interval  $i$ , while  $\Delta EX(i)$  indicates the amount of energy exchanged between the Microgrid and the external grid. As for the price indicators,  $Q(i)$  represents the TOU tariff, while  $Q'(i)$  represents the implicit penalty for energy export, which is a given positive value when  $\Delta EX$  is greater than 0 and equals to zero in other cases.

When assigning  $\Delta EX$  with the forecasted energy exchange values, such formulation will derive a series of dispatch signals for the battery system over the upcoming  $N$  intervals. Since the forecast is an iterative process with improved accuracy as time horizon decreases, only the 1<sup>st</sup> of the  $N$  dispatch signals is set as the real dispatch signal of the battery system for the nearest future time slot (i.e.,  $i = 1$ ). After the hour of operation, the measured renewable production, industrial load and the dispatched energy from the battery for that hour are utilized for calculating the real cost value.

## V. Case study with simulation results

By using the data collected in May 2013, two simulation-based case studies are carried out to compare the economic performance of the battery system under different conditions. In all cases,  $\eta_c$  and  $\eta_d$  are both set to 90%. Further,  $\lambda$  is set to 1 and  $Q'(i)$  is set to 10000 RMB to mimic a heavy penalty on any energy export.

### Case 1. Perfect forest vs. Imperfect forecast

In this case, the operational range of battery's SOC is set as 10% - 90%. When varying the length of forecast horizon (i.e.,  $N$ ) considered in the dispatch program, the real monthly costs for both arbitrage and export under perfect forecast and imperfect forecast conditions respectively are depicted as in Figure 3. The prefect forecast assumes 100% forecast accuracy while the imperfect forecast is generated by the earlier mentioned forecasting machine.

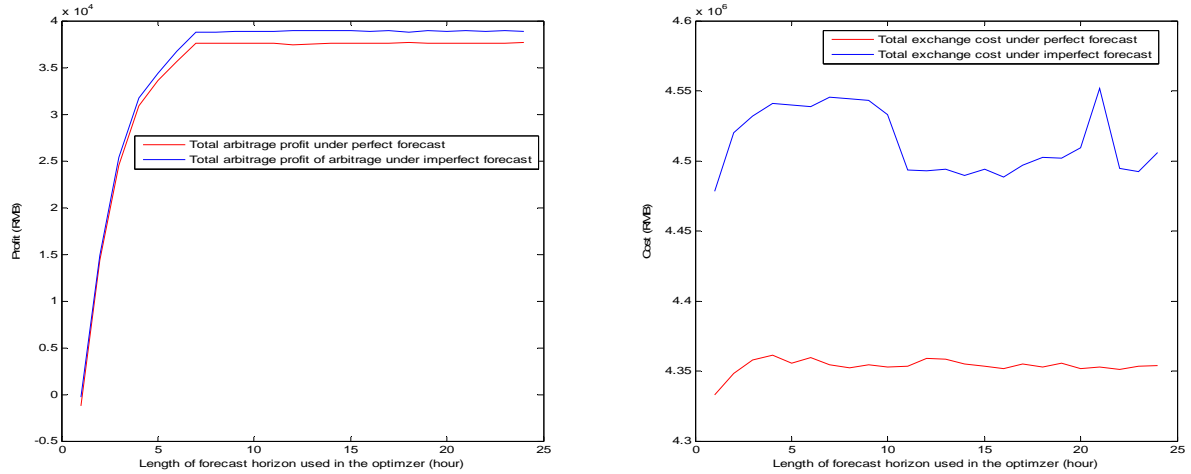


Figure 3. Cost comparison between the dispatch program's performance under both perfect and imperfect forecast with a varying forecast horizon

As found in this comparison, the best arbitrage performance can be reached without having to consider an entire 24-hour forecasting horizon. Further, since the forecasting machine tends to under-estimate the amount of energy export, the battery system could therefore realize more arbitrage profit than the case under perfect forecast. On the contrary, this special characteristic of the forecasting machine results in almost 5% more exchange cost for all different forecast horizons considered. For the case of dispatch using imperfect forecast, the minimum dispatch cost expressed in (1) is found when the length of forecast horizon considered in the dispatch program is 16.

### Case 2. Large operational SOC range vs. Small operational SOC range

In this case, the length of forecast horizon considered in the dispatcher is set to 16. Instead of using the SOC range 10% - 90%, a manufacturer recommended SOC range 20% - 80% is selected for comparison. For the two cases, the battery's lifecycle consumption during the simulated period is estimated by using the rainflow algorithm described in [2]. The estimated partial lifecycle consumption as in Figure 4, is further converted into the temporal life consumption in percentage of its total life

when a typical lifecycle vs. DOD curve from [3] is used. As the result Table 2 shows, in the simulated context, the dispatch program with a larger SOC range leads to a better solution.

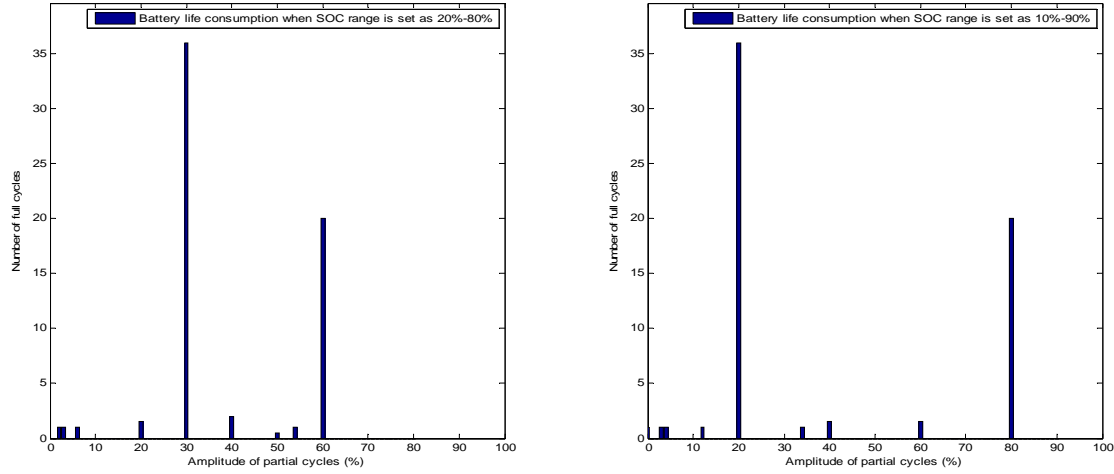


Figure 4. Estimated partial lifecycle consumption under different SOC ranges

Table 2: Summary of simulation results for case 2

|               | Arbitrage profit (RMB) | Total cost (RMB)   | Life consumption (%) |
|---------------|------------------------|--------------------|----------------------|
| SOC 20% - 80% | $3.55 \times 10^4$     | $4.52 \times 10^6$ | 1.38                 |
| SOC 10% - 90% | $3.91 \times 10^4$     | $4.49 \times 10^6$ | 1.35                 |

## VI. Conclusion

The paper has described a multi-objective oriented battery dispatch solution that is developed based on a practical industrial Microgrid application with high renewable production. By deploying the optimal dispatch solution, both objectives, i.e., energy arbitrage and exported energy reduction can be achieved. Two important design aspects of the dispatch solution, i.e., forecast and operational range of battery's SOC are analysed based on simulated case studies. The described dispatch solution can be easily extended to include other dispatchable resources into the formulation.

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